

A ROSAT WFC observation of SW UMa: the EUV behaviour of dwarf novae in superoutburst explained

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ABSTRACT

During re-processing and analysis of the entire *ROSAT* Wide Field Camera (*WFC*) pointed observations database, we discovered a serendipitous, off-axis detection of the cataclysmic variable SW UMa at the onset of its 1997 October superoutburst. Although long outbursts in this SU UMa-type system are known to occur every ~ 450 days, none had ever been previously observed in the extreme ultra-violet (EUV) by *ROSAT*. The *WFC* observations began just ≈ 13 hr after the optical rise was detected. With a peak count rate of ~ 4.5 count s^{-1} in the S1 filter, SW UMa was temporarily the third brightest object in the sky in this waveband. Over the next ≈ 19 hr the measured EUV flux dropped to < 2 count s^{-1} , while the optical brightness remained essentially static at $m_v \sim 11$. Similar behaviour has also been recently reported in the EUV light curve of the related SU UMa-type binary OY Car during superoutburst (Mauche and Raymond 2000). In contrast, U Gem-type dwarf novae show no such early EUV dip during normal outbursts. Therefore, this feature may be common in superoutbursts of SU UMa-like systems. We expand on ideas first put forward by Osaki (1994, 1995) and Mauche and Raymond (2000) and offer an explanation for this behaviour by examining the interplay between the thermal and tidal instabilities which affect the accretion disks in these systems.

Key words: accretion, accretion disks – stars: binaries: close – stars: individual: SW UMa

1 INTRODUCTION

Cataclysmic variables (CVs) are close binaries in which mass transfer is taking place. The primary star is a degenerate white dwarf and the secondary a late-type K or M dwarf. The orbital periods are typically measured in hours, and in non-magnetic CVs an accretion disk is commonly formed around the white dwarf. One group of CVs which undergo quasi-periodic outbursts is called the dwarf novae (DN). Outbursts are thought to occur as a result of increased accretion onto the white dwarf due to instabilities in the disk. For a review of these binaries, see Warner (1995).

SW UMa is a member of the SU UMa class of dwarf novae. These systems have orbital periods ≤ 2 hr and show at times longer, brighter outbursts called superoutbursts. The cause of these superoutbursts has been proposed to be a combination of the disk instability plus an additional tidal instability (Osaki 1995). SW UMa itself (orbital period ≈ 81 mins) displays outbursts every ~ 450 days (Ritter and Kolb 1998).

On 1997 October 18th SW UMa was reported to be in superoutburst (Mattei et al. 1997), reaching a peak vi-

sual magnitude $m_v \approx 10.4$ at 1997 October 19.969.^{*} Coincidentally, ≈ 13 hr later (at 1997 October 20.549) SW UMa was serendipitously detected and observed with the *ROSAT* *WFC*. At this point, SW UMa was one of the brightest objects in the EUV sky. The *ROSAT* observations continued over the next ≈ 19 hr.

2 THE ROSAT WFC OBSERVATION

Launched on 1990 June 1, *ROSAT* carried two co-aligned instruments, an X-ray telescope and the Wide Field Camera (Sims et al. 1990) covering the EUV waveband. After an initial 6-month survey phase a programme of pointed observations began, continuing until the mission terminated in February 1999. Most observations with the *WFC* were conducted through one of two broad-band filters, S1 which

^{*} Note that Howell et al. (1995) would only have classified the outburst as intermediate since it was neither as bright nor as long (~ 16 days, see Fig. 1) as previous superoutbursts.

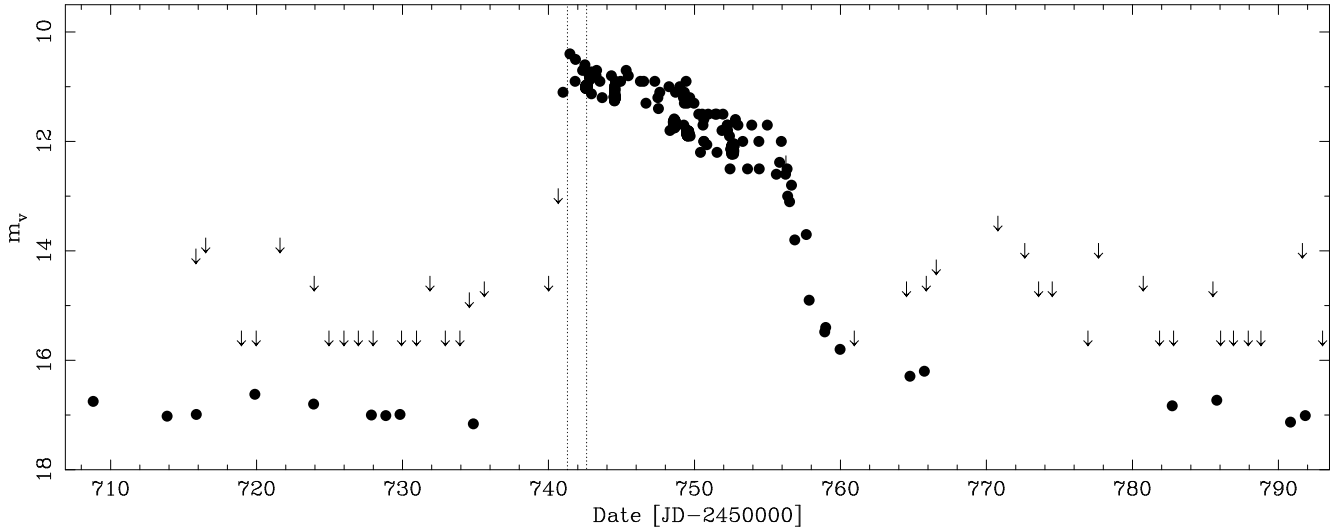


Figure 1. Optical light curve of the October 1997 superoutburst of SW UMa, from AAVSO records (Mattei 2000). The arrows indicate upper limits on the observed magnitude. The dotted vertical lines indicate the extent of the simultaneous *ROSAT* *WFC* observations.

covered the range 60–140 Å (90–200 eV), and S2 which covered 112–200 Å (60–110 eV).

We are currently re-processing and analysing the entire database of *WFC* pointed phase observations (Pye et al., in preparation). In the course of this work, we discovered a serendipitous off-axis detection of SW UMa in superoutburst, during a pointed observation of the quasar 4C+55.16 (*ROSAT* observation sequence number 703892). The S1 filter was in place throughout the observation, which began at 1997 October 20.549. SW UMa was visible near to the edge of the detector, 126.5′ off-axis. Since the field of view of the *WFC* is much greater than that of the X-ray instrument in use at the time (the High Resolution Imager), it was not seen by that telescope (the *WFC* has a field of view $\approx 5^\circ$ in diameter, the HRI $\approx 30'$). The observation lasted for ≈ 19 hr, although SW UMa was not observed continuously due to various observing constraints (e.g. earth occultation, passage through radiation belts, scheduling of other astronomical targets).

SW UMa had not previously been detected with the *ROSAT* *WFC* in a pointed phase observation. Rosen et al. (1994) detected the system in quiescence with the Position Sensitive Proportional Counter (*PSPC*) in 1992 April/May, but it was not seen by the *WFC* at that time. However, it was marginally (3.1σ) detected during the *WFC* all-sky survey, in the S1 filter, when it was also in quiescence. Wheatley (1995) measured the survey count rate at $0.0075 \text{ count s}^{-1}$ (68% confidence range $0.0044\text{--}0.011 \text{ count s}^{-1}$). The system has been observed once before in the EUV/soft X-ray regime during superoutburst, by *EXOSAT* during March 1986 (Szkody, Osborne and Hassall 1988). On that occasion, it was detected by the low energy detector LE1’s 3000 Lexan filter (0.05–2.0 keV) and also in the Al/P filter (0.04–0.08, 0.13–1.8 keV), but not by the medium energy ME detector. The 3000 Lexan filter count rate increased by a factor 44 above its quiescent value.

3 ANALYSIS

3.1 The optical and EUV light curves

Figure 1 shows the 1997 October optical light curve across the whole of the superoutburst (from AAVSO records, Mattei 2000). The dotted vertical lines indicate the position of the *WFC* observation, for comparison. Note that in the optical the plateau phase lasted for ~ 15 days, during which the brightness declined steadily from a peak of $m_v \approx 10.4$ to $m_v \approx 13.5$. It then rapidly declined back to quiescence.

The EUV light curve (Figure 2) was constructed using the Starlink software Asterix (Allan and Vallance 1995) together with the *WFC* data reduction package WFCPACK (Denby and McGale 1995). The count rates have been corrected for detector degradation and are equivalent to “at launch” values.[†]

The source was brightest in the EUV at the start of the *WFC* observation, at a count rate of $\sim 4.5 \text{ count s}^{-1}$, ≈ 13 hr after the optical outburst had been first observed. At this point, it was the third brightest object in the EUV sky between 60–140 Å, after the steady white dwarf sources HZ43 ($\sim 14.5 \text{ count s}^{-1}$) and H1504 ($\sim 4.8 \text{ count s}^{-1}$). It had also brightened by a factor 400–1000 over the quiescent *WFC* count rate measured by Wheatley (1995).

Over the next ≈ 19 hr the measured EUV flux declined by a factor ~ 2.5 , in contrast to the optical brightness, which was essentially static but declined by no more than a factor ~ 1.5 . The EUV flux then appeared to level out at $\sim 1.7 \text{ count s}^{-1}$.

[†] Over the course of its operational lifetime the sensitivity of the *WFC* degraded significantly. In particular, the spacecraft accidentally pointed near the Sun in 1991 January, resulting in a factor ~ 7 decrease in the detector sensitivity. By 1997 October, when these observations of SW UMa were made, the sensitivity was just 0.11 of that “at launch”. A full description of the *WFC* calibration history will be given by Pye et al. (in preparation).

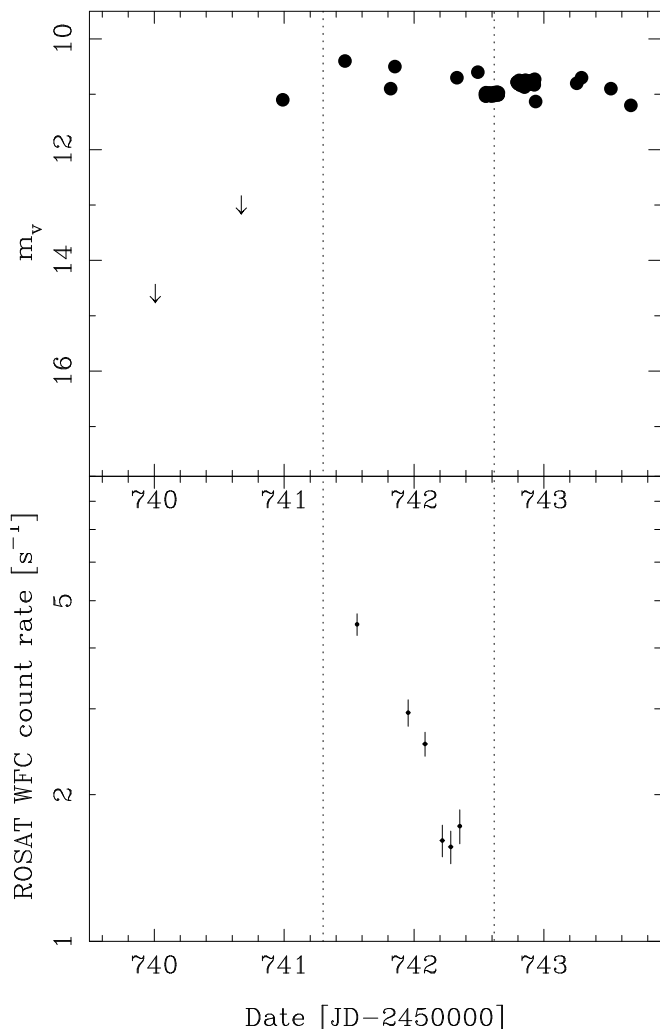


Figure 2. Bottom: the EUV light curve obtained by the *ROSAT* WFC. The corresponding section of the optical light curve is shown above for comparison.

3.2 A period search on the EUV light curve

We have conducted a period search on the SW UMa WFC data, in particular to search for any evidence of the ≈ 81 minute orbital period, ≈ 84 minute “superhump” period, and other shorter periods such as a 15.9 minute optical period reported by Shafter, Szkody and Thorstensen (1986), which may be associated with the rotation period of the white dwarf. The data were binned in 30 second intervals for this analysis but the period search proved negative. A search for faster periods such as possible dwarf novae oscillations, using data binned at one second intervals, also proved negative.

4 DISCUSSION

4.1 The 1997 EUV superoutburst light curve

The rapid decline in the EUV luminosity of SW UMa so soon after rising to superoutburst is surprising. For example, the EUV light curves of the dwarf novae U Gem and

SS Cyg during normal outbursts follow the behaviour of the corresponding optical light curves throughout the optical plateau phase and during the subsequent rapid decline (e.g Long et al. 1996, Mauche 1998). No rapid decline in the brightness of the EUV light curve is seen so early in the outburst.

However, similar behaviour to that seen here in SW UMa has been reported recently in the superoutburst EUV light curve of the related SU UMa-type system OY Car (Mauche and Raymond 2000). This binary was observed for just over three days by the Extreme Ultraviolet Explorer (*EUVE*) shortly after it went into superoutburst in March 1997. The Deep Survey instrument light curve declined rapidly from a peak brightness of ≈ 0.21 count s^{-1} at the start of the observation, to ≈ 0.07 count s^{-1} after just ~ 1.5 days. The optical light curve declined much more slowly over the same period. Then, perhaps more surprisingly, the EUV brightness increased after ~ 2.5 days to ≈ 0.1 count s^{-1} (see Figure 2 of Mauche and Raymond 2000). Mauche and Raymond draw comparisons to similar behaviour in the Voyager FUV light curve of VW Hyi in superoutburst (Polidan and Holberg 1987). An early EUV/soft X-ray dip may also be present in that object’s corresponding *EXOSAT* light curve (Pringle et al. 1987).

We now offer an explanation for the behaviour of the EUV light curves of SU UMa-type binaries during superoutburst, in terms of the interplay between the thermal and tidal instabilities which affect the accretion discs in these systems. We expand on the ideas put forward by Mauche and Raymond (2000) for the behaviour seen in OY Car and VW Hyi, and first discussed by Osaki (1994, 1995). We assume that the decline in the WFC count rate represents a true decrease in the total EUV flux. With observations in a single filter we cannot rule out the possibility that the observed drop in count rate is instead due to a spectral variation (e.g. a decrease in temperature)[‡], although we consider this unlikely.

The lightcurves of SU UMa systems show frequent, relatively short and weak normal outbursts interspersed by long, large amplitude superoutbursts. The normal outbursts are thought to arise because of a thermal-viscous driven disc instability due to the partial ionization of hydrogen (see Cannizzo 1993 for a review). Each normal outburst only involves the accretion of a small fraction of the total disc mass onto the white dwarf. Consequently, there is a gradual accumulation of mass and angular momentum in the disc. As a result, the outer disc radius expands until the tidal resonance radius is reached (in systems with a mass ratio below ~ 0.33 , a resonance arises because of a 3:1 commensurability between the disc and binary frequencies, Whitehurst and King 1991). At this point the enhanced tidal interaction between the disc and the secondary star removes angular momentum from the outer disc and inhibits further evolution of the disc radius. Osaki (1995) proposed that the superoutbursts of SU UMa systems arise because of this thermal-tidal instability which spreads through the disc via a heating wave, on the short thermal timescale. The tidal interaction subse-

[‡] Wheatley et al. (1996a) and Wheatley et al. (1996b) discuss the possible effects of spectral variations in dwarf novae on observed WFC count rates.

quently increases the mass accretion rate through the disc, triggering a superoutburst.

The observed EUV emission from an SU UMa star in outburst is produced by the hot, inner regions of the accretion disc. Once in outburst the surface density of the inner disc, and hence the resulting EUV emission, will decay on the timescale $t_{\text{visc}} \sim R^2/(\alpha c_s H)$, where R is the radius within the disc, α is the Shakura-Sunyaev viscosity parameter, c_s is the local sound speed and H is the disc semi-thickness (Frank, King and Raine 1992). Typical parameters of the inner disc in outburst ($R \sim 10^9$ cm, $\alpha \sim 0.1$, $c_s \sim 10$ km s $^{-1}$, $H \sim 0.1R$) yield $t_{\text{visc}} \sim 1$ day. However, as outlined above, in a superoutburst the expansion of the accretion disc causes the tidal radius to be exceeded and the tidal instability to set in. The EUV emission rate recovers when the inner disc is resupplied with mass as the tidal instability increases the mass transfer rate through the disc. We can estimate the timescale for the growth of the tidal instability from the delay between the time of super-maximum and the first appearance of superhumps in the optical light curve (superhumps are small-amplitude modulations seen in the optical light curves during superoutburst, and are caused by the accretion disc becoming eccentric due to the action of the tidal instability). This timescale is between 3–7 days in the case of SW UMa (see Warner 1995, Table 3.7 and references therein). So, if we associate the observed EUV emission of SW UMa with viscous dissipation in the inner regions of the accretion disc we can understand the decline seen after super-maximum as the reduction in the surface density of the inner disc during outburst, with an expected e-folding time of ~ 1 day. We predict a subsequent rise in the EUV flux after $< 3 - 7$ days, as the inner regions of the disc are re-supplied with mass by the action of the tidal instability, although none is seen in the data presented here since the ROSAT WFC observation ended ~ 1 day after the start of the optical superoutburst. The optical light curve remains approximately constant during this period as the optical emission of the accretion disc is dominated by its outer regions, where the surface density decays on a much longer timescale.

The observations of OY Car by Mauche and Raymond are also in agreement with this picture. The EUV light curve is seen to decay over 1.5 days, close to the viscous timescale of the inner disc, and recover after ~ 2.5 days; the time between supermaximum and the first appearance of superhumps in the optical light curve in this system is $\sim 2 - 3$ days (Warner 1995).

We suggest that the behaviour seen here in the EUV light curve of SW UMa, by Mauche and Raymond (2000) in OY Car, and possibly in the EXOSAT soft X-ray light curve of VW Hyi (Pringle et al. 1987), is a common feature of superoutbursts in SU UMa systems, compared with normal outbursts in U Gem-like dwarf novae. The EUV light curves can, therefore, provide both observational clues to the superoutburst mechanism and an observational means of discriminating between normal outbursts and superoutbursts in these systems. It is unfortunate that the last major mission observing the EUV section of the electromagnetic spectrum, *EUVE*, has recently been terminated by NASA. No new observatories are planned for this waveband in the near future.

4.2 Transients observed in the EUV

At peak brightness, at the start of the *WFC* observation, SW UMa was the third brightest object in the EUV sky between 60 – 140 Å, and the fourth brightest object ever seen by the *WFC*. The brightest was the EUV transient RE J1255+266, observed in 1994 June with the S2 filter at a peak degradation-corrected count rate of 76.5 count s $^{-1}$ (Dahlem et al. 1995). Watson et al. (1996) subsequently showed that RE J1255+266 was a WZ Sge type CV system in outburst (we discuss this outburst in more detail in the Appendix). Bright transient events have also been seen by *EUVE*. For example, U Gem was one of the brightest objects in the EUV sky during its 1993 December outburst when it was monitored by *EUVE* (Long et al. 1996). The EUV sky monitor *ALEXIS* has also observed a variety of transients, including cataclysmic variables in outburst, such as the SU UMa-type binary VW Hyi (Roussel-Dupree and Bloch 1996). Clearly, then, during outburst cataclysmic variable systems can provide some of the most intense sources of EUV radiation in the sky. However, we also note that *ALEXIS* observed a number of shorter ($\lesssim 1$ day) transients of unknown origin and nature. These events could be previously unrecognised CVs or, for example, due to geocoronal stellar flares.

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APPENDIX: The EUV transient RE J1255+266 – a normal or superoutburst of a WZ Sge system?

The exceptionally bright EUV transient source RE J1255+266 was discovered by the *ROSAT* WFC in 1994 June during rapid exponential decline (Dahlem et al. 1995). The WFC count rate decreased exponentially over a period of four days, with an e-folding time of about one day. The rise was not covered, and the source was not detected in another WFC observation eight days later, consistent with a continuing exponential decline. The outburst was not observed optically. Watson et al. (1996) later identified the optical counterpart spectroscopically and concluded that it was probably a WZ Sge-type CV system that had been in superoutburst (WZ Sge systems, a subset of the SU UMa's, appear to show a strong preference for superoutbursts that last weeks, rather than normal outbursts which last for a few days). Recently, though, Wheatley, Burleigh and Watson (2000) have shown that the object was in quiescence just four days before the discovery observation, and concluded that this was most likely only a normal outburst of a WZ Sge system. The superoutburst EUV light curve of SW UMa (Figure 2), together with the *EUVE* observation of OY Car discussed by Mauche and Raymond (2000), now raises the possibility that the rapid EUV decline of RE J1255+266 actually occurred at the beginning of a much longer optical superoutburst. However, both SW UMa and OY Car show an EUV decline for $\lesssim 1$ day, which then flattens off and possibly rises again. In RE J1255+266 the decline continued at a constant exponential rate for at least 4 days and probably for more than 12 days. We take this as further evidence that the outburst of RE J1255+266 detected by *ROSAT* was probably a normal outburst of a WZ Sge CV system, not a superoutburst.